

THESIS/REPORTS

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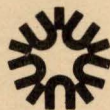
USE OF PHOTO INTERPRETATION AND REMOTE
SENSING TECHNIQUES TO ESTABLISH HAZARD RATING
CRITERIA FOR SPRUCE BUDWORM SUSCEPTIBLE STANDS

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FINAL REPORT
May 30, 1981

Forest, Wildlife and Range Experiment Station



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1. INTRODUCTION

Remote sensing techniques offer the forest manager a means to cover large and inaccessible areas in a short period of time. Our hypothesis is: the identification and mapping of fir stands susceptible to western spruce budworm can be facilitated by the use of existing aerial photographs.

Past experience has shown that moderate and severe damage from the spruce budworm can be seen and plotted on maps by aerial observers. Photo interpretation of color and color infrared aerial photography also detects foliage damage when taken at the proper scale and time of year. In fact, the detection of lighter defoliation levels can be assessed more accurately on color photos at a scale of 1:4,000 or larger than by visual observations.

However, detecting and plotting defoliation damage has been helpful mainly in determining population trends and areas needing control action. Little consideration has been given toward identifying factors, such as stand, site and physiographic location, which may render a forest stand susceptible to future spruce budworm damage. The study described herein addresses precisely that problem.

Our objective is to identify which independent variables such as: slope, aspect, percent of host tree species, elevation, crown diameter, topographic position, and total stand density are significantly correlated

with spruce budworm defoliation. Only variables will be selected that can be measured on existing aerial photographs and maps. If we discover that these variables can be related to presence and possibly degree of spruce budworm foliage damage, we can offer the forest manager a tool to evaluate his stands for susceptibility to budworm attack. The manager then has the option to consider alternative silvicultural treatments on these stands in the expectation of reducing future losses. This is an approach advocated by forest entomologists (Graham, 1956) and silviculturalists (McLintock, 1949) for many years.

2. STUDY AREAS

During the course of this investigation, three different study areas were located on: 1) the Clearwater National Forest near Pierce, Idaho, 2) the Okanogan National Forest near Twisp, Washington, and 3) the Payette National Forest near McCall, Idaho (Figure 1).

The study began in the spring of 1978 on the Pierce area because of its past defoliation history and its proximity to the University of Idaho. Due to the dramatic drop in the western spruce budworm (WSB) population in 1978 at Pierce, the Twisp area was chosen for study during 1979. Although WSB populations were down in the Twisp area in 1979, sufficient defoliation existed to obtain meaningful data. The McCall area was selected in 1980 for purposes of model validation and to obtain more data in heavily defoliated fir stands.

The Pierce study area is located approximately five miles east of Pierce, Idaho on the Pierce Ranger District. Climate for the region is typified by mild wet winters and hot dry summers. Annual precipitation averages 30 to 35 inches with 30 to 40 percent occurring during the

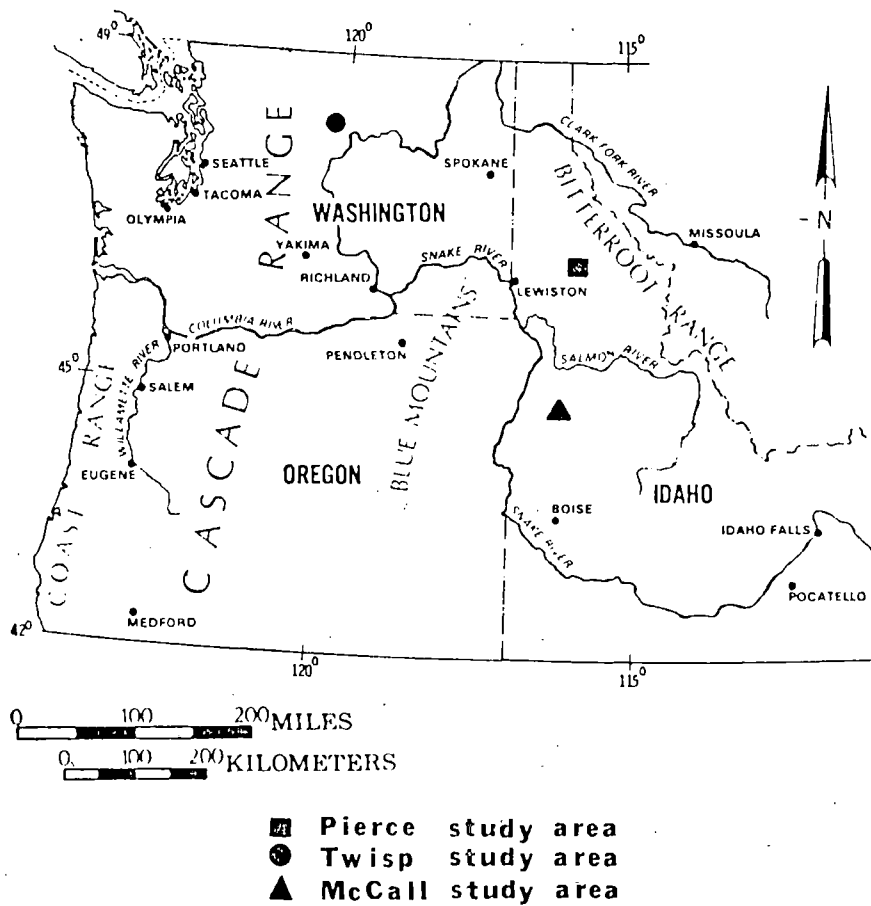


Figure 1. Locations of study area.

winter months of December, January and February. Forest stands are quite diverse in species and densities. Tree species include: cedar (Thuja plicata Donn.), Douglas-fir (Pseudotsuga menziesii (Mirb) Franco), grand fir (Abies grandis (Dougl.) Forbes), subalpine fir (Abies lasiocarpa (Hook.) Nutt.), larch (Larix occidentalis Nutt.), ponderosa pine (Pinus ponderosa Laws), lodgepole pine (Pinus contorta Dougl. ex Laud), Engelmann spruce (Picea engelmannii Parry), white pine (Pinus monticola Dougl.), western hemlock (Tsuga heterophylla (Raf) Sarg.) and mountain hemlock (Tsuga mertensiana (Bong.) Carr.). All of the study plots fell into either the western hemlock or subalpine fir series (Daubenmire and Daubenmire, 1968).

The Twisp area is located on the western side of the North Cascades on the Twisp River drainage approximately 25 miles west-northwest of Twisp, Washington. It is a topographically mature area of great relief. Valleys are uniformly very deep and steep sided. These mountains are to a large extent comprised of ancient sedimentary rocks, most of which are folded and at least partially metamorphosed. Intrusions of large granitic batholiths are also common (Franklin and Dyrness, 1973). Weather in the region features a combination of both maritime and continental climates. Mountain masses have a profound effect on the climatic regime. Summers are fair and sunny and the winters are moderately cold with frequent heavy snowfall. Mean annual precipitation averages 25 to 30 inches with about one-half falling in the winter months of December, January and February. Forest communities are characterized by Engelmann spruce and subalpine fir in the stream bottom with a few cedar at lower elevations. At lower elevations above the stream bottoms, ponderosa pine and Douglas-fir dominate. As elevation increases, ponderosa pine disappear and almost pure stands of Douglas-fir result; Douglas-fir and subalpine dominate at high elevations. Lodgepole pine is also present at all elevations up to timberline.

The McCall study area is located in and around the town of McCall, Idaho, and extends south to Cascade, Idaho. The easternmost plots are located at Gold Fork and westernmost at Cuprum, Idaho. The McCall section consists primarily of rugged mountains composed of granitic rocks of the Idaho Batholith. Soils from the granitic parent materials are moderately coarse to coarse textured throughout their profiles (Steele et al., 1975). The study plots located near Cuprum contain relatively low gentle mountains and the most extensive rock type is Columbia River basalts. Soils are often deep and loamy and may contain loess and volcanic ash. Precipitation averages 30 to 35 inches a year with most occurring between November and March. Winters are quite cold when there are cold air masses from Canada. Summers are cool because of high elevations (1,500 to 2,300 m) and the influx of cool Canadian air. Valleys and canyons occasionally become quite hot. The distribution of tree species in central Idaho appears as a continuum but their potential to dominate communities at climax does not (Steele et al., 1975). Grand fir readily dominates until it reaches its southern environmental limit. Engelmann spruce, Douglas-fir, subalpine fir, larch, ponderosa and lodgepole pine are also present in various mixtures and densities. There are very few if any naturally occurring pure stands. The grand fir found in this area occupies a zone of intergradation between grand fir and white fir.

3. METHODS AND PROCEDURES

a. General

The study areas were selected within boundaries of a known WSB outbreak as described on aerial sketch maps of previous years. Size of the study areas varied but total size for each location (Pierce,

Twisp, and McCall) was approximately 100 square miles (Figure 2).

The areas were broken into equal sized blocks, one-half by two miles in size. Thirty sample blocks were chosen at random for both Pierce and Twisp and 20 for the McCall area.

The sample blocks were stratified using crown condition class maps for the Pierce area and ecotype maps for Twisp. Crown condition class and ecotype maps are derived from photo interpretation of medium scale aerial photography and are methods of stratifying forest types based on tree height, tone, texture, etc. The type maps were subdivided to a 10 acre minimum by physiographic location (ridge, side-hill, bottom) and the subdivisions were defined as a forest stand.

Data gathering techniques for the McCall area were similar to those used in previous years with the exception of sample design. The McCall study area was stratified by defoliation class (high, medium, low) as sketch mapped from the air by the Forest Pest Management (FPM) Division of the Forest Service, USDA during 1979. Twenty large scale aerial photographic sampling blocks, as described above, were allocated to each stratum proportional to the area of each stratum. The allocated blocks were then randomly located within each stratum. Sample size calculations based on variances acquired from the best predictive model developed for Twisp indicated a sample size of approximately 130 for McCall. This sample size is based on an estimate of defoliation within plus or minus 10 percent at the .05 significance level. Because of the large data sets required by the planned nonlinear regression techniques (greater than 500 plots), 658 aerial photo sampling plots were taken, representing 12 blocks.

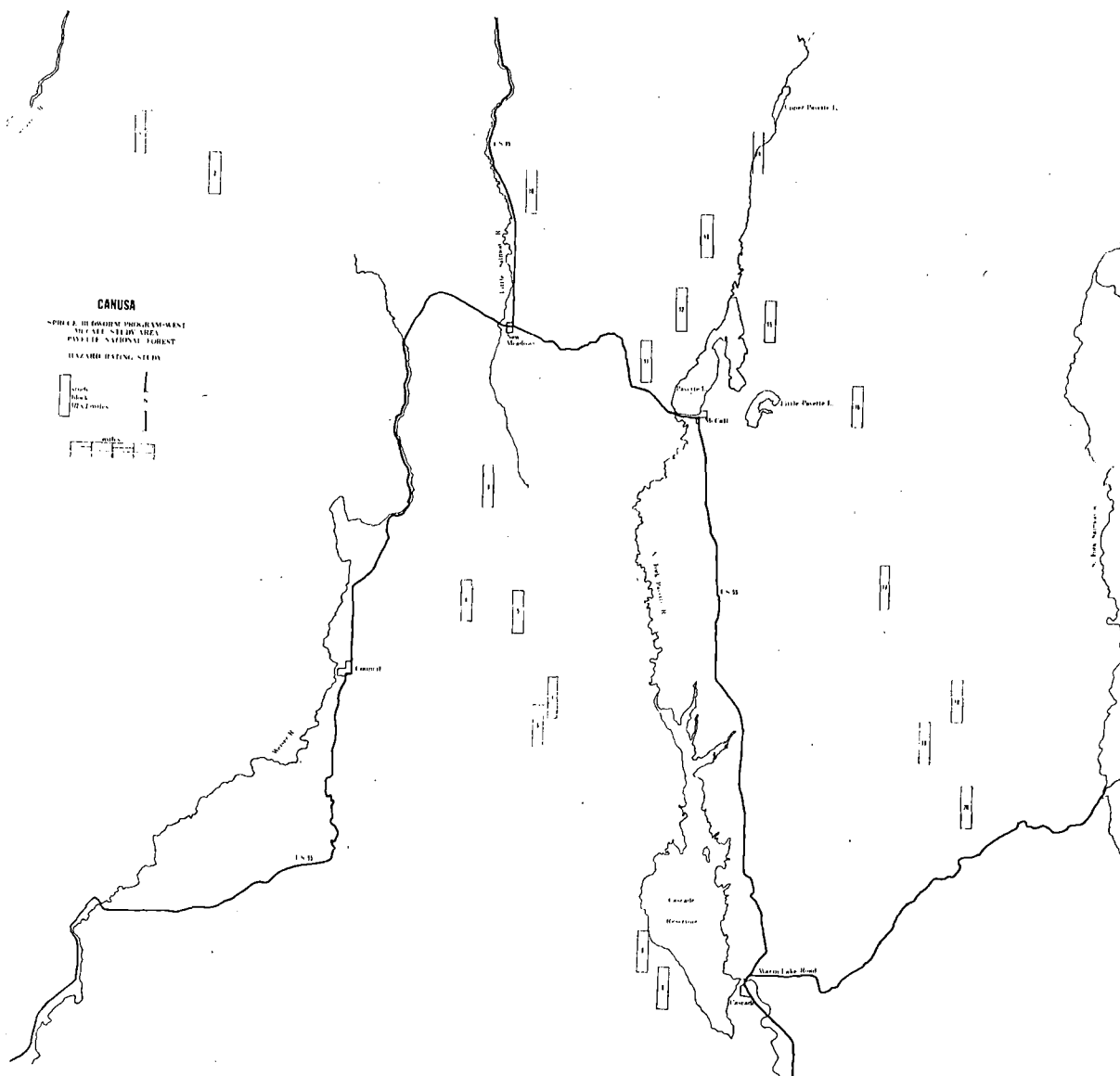


Figure 2. Spruce budworm outbreak area with aerial photographic sample blocks for McCall, Idaho.

Color transparency aerial photographs were taken with a 9 by 9 inch format camera (Fairchild KA-2) at a scale of 1:4,000 using a 12-inch focal length lens and Kodak Aerochrome 2448 film. Timing of the photography was planned to correspond with peak discoloration of clipped and webbed needles. The Pierce area was photographed September 20, 1978, Twisp was taken July 17, 1979, and McCall was photographed July 22-23, 1980. Although the original plan for 1980 was to photograph Twisp again, information supplied by Roy Beckwith of the Pacific Northwest Range and Experiment Station indicated a sharp decline in WSB population levels. Roy felt that an area near Twisp on the Conconully District of the Okanogan National Forest had a larger population of WSB. The Conconully was photographed July 25, 1980 and the defoliation levels did seem higher than those at Twisp, but an initial interpretation of the photography indicated defoliation levels below 40 percent. For this reason the photography was not used.

After the film was processed and returned, ground examination plots were selected. The selection was based on defoliation levels, tree size, tree species and relative accessibility. A variety of selection criteria was chosen to cover a broad range of ground conditions. Photo enlargement (2x) of ground plots were made for Pierce and Twisp but not for McCall due to a time constraint. The enlargements were used to aid in plot and tree location and for documentation of field observations.

Ground plots were visited and current and past defoliation information (field forms, Appendix A) was taken both by optical rating and on four mid-crown branches. A pole pruner or shotgun was used to fell the branches. Tree species, height and crown diameter

information was also taken. Ground plot information was compiled and used for calibration and reference during photo interpretation.

b. Photo interpretation of independent variables and defoliation

The large scale (1:4,000) color transparencies were labeled with appropriate flight line numbers, cut from the roll and placed in transparent sleeves or laminated on both sides with .0015 inch heat sensitive clear plastic film (Befort et al., 1980). A binocular equipped Nikon mirror stereoscope mounted on a heavy base was used for stereo viewing of the transparencies. Magnifications of both 1x and 3x were used.

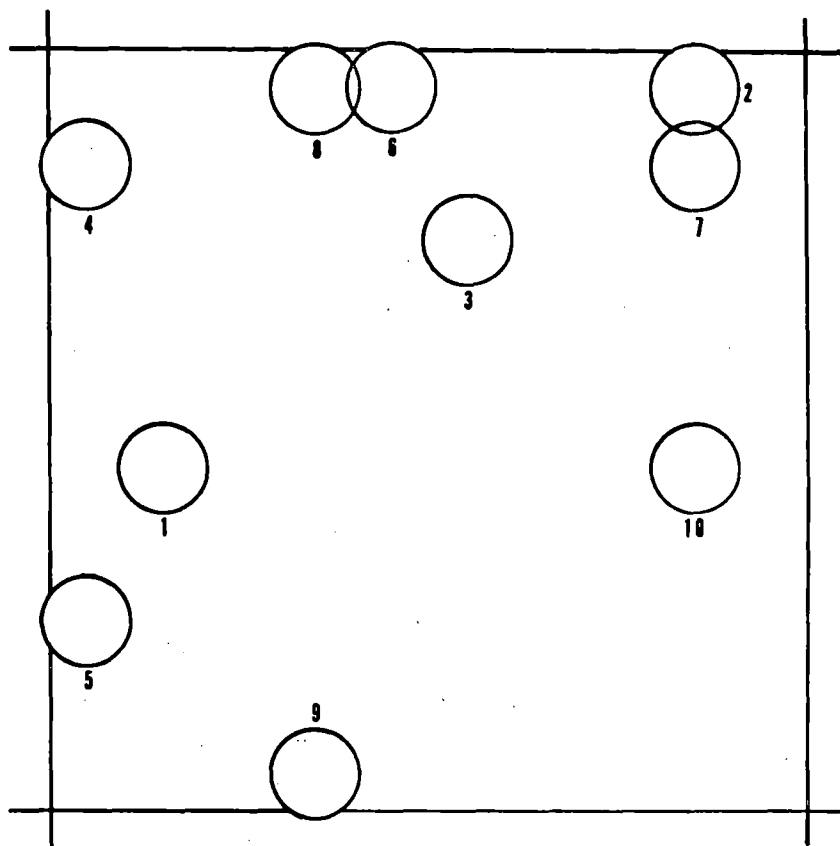
Plots which had no host trees or were presently being logged were not evaluated. Due to extremely low WSB populations at Pierce in 1978, no defoliation was evident on the aerial photographs. Photo plots were limited to areas where ground examination of defoliation was done. Plot defoliation information was furnished by Karel J. Stoszek's crews who were working on a hazard rating study using data collected on the ground (Stoszek et al., 1979). For the Twisp area, a 10 percent photo sample (1 acre plot for every 10 acres stand size) was used. For the McCall area a 10 percent random photo sample template (Figure 3) was used (64 plots per one-half by two mile block) on the 12 selected blocks. The one acre photo plots were interpreted for the following data:

Elevation: The elevations for each stand in the Pierce and Twisp areas and for each plot at McCall were determined from U.S.G.S. 1:24,000 topographic maps and rounded to the nearest 10 feet.

Slope: Slope measurement on aerial photographs with a parallax bar is both tedious and time consuming. Analysis of results from a

RANDOM PHOTO PLOT GRID

10 Percent Sample Plot = 1 acre



psr = 4000

Figure 3. Ten percent random photo plot template (not to scale) was used to locate plots on alternate stereo photographs.

similar hazard rating study for DFTM (Heller et al., 1977) showed no significant loss in hazard prediction accuracy using a three category slope variable (0-15%, 15-65%, and >65%) when compared to slopes measured to the nearest five percent with a parallax bar. To aid in the process of interpretation of slope into these categories a slope comparator was developed (Figure 4). The comparator consists of a pair of cones whose side slope is the same as the break off points for the slope classes (15 and 65 percent). The cones are mounted on a plexiglas arm which makes for rapid and easy adjustment for different photo separations and crab. The comparator proved quite useful, and after a bit of use only slopes which approached the cutoff needed to be compared.

Topographic location: The physical location of each plot was placed into one of three categories: ridge (1), sidehill (2), or bottom (3). A ridge plot had to surround an area which had a high point and more than one slope. Aspect and slope were measured in the direction with the greatest amount of defoliation or in the direction with the highest concentration of trees. Defoliation took precedence over the concentration of trees. A sidehill plot had to be on a hillside with basically only one slope and direction. A bottom plot had to surround an area which was at the base of one or more slopes (e.g., ravine, stream, valley). The aspect and slope were measured in the direction of the drainage (Figure 5).

Aspect: A template was constructed (Figure 6) based upon 16 points of the compass, every 22.5 degrees, beginning at zero degrees or north. This template was oriented on the photos according to the direction of flight. The aspect for each plot was determined by

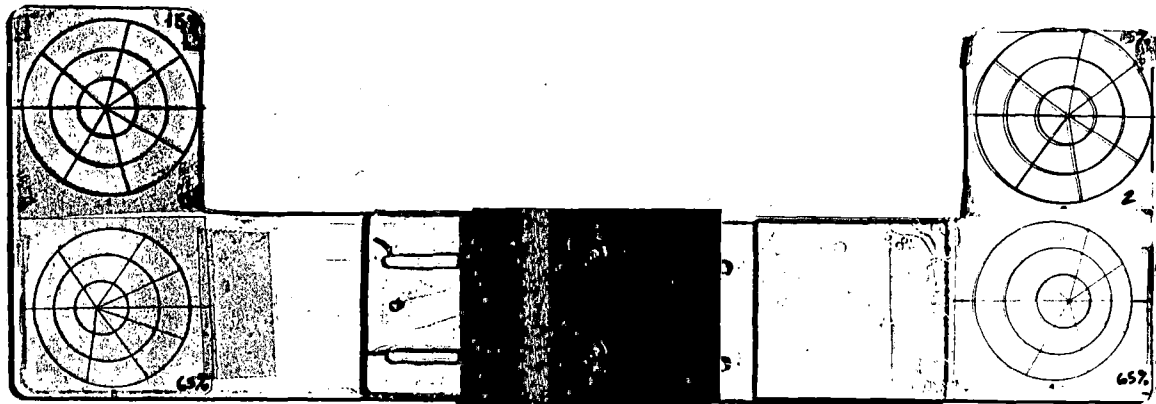


Figure 4. Slope comparator template developed for placing slopes into discrete slope classes.

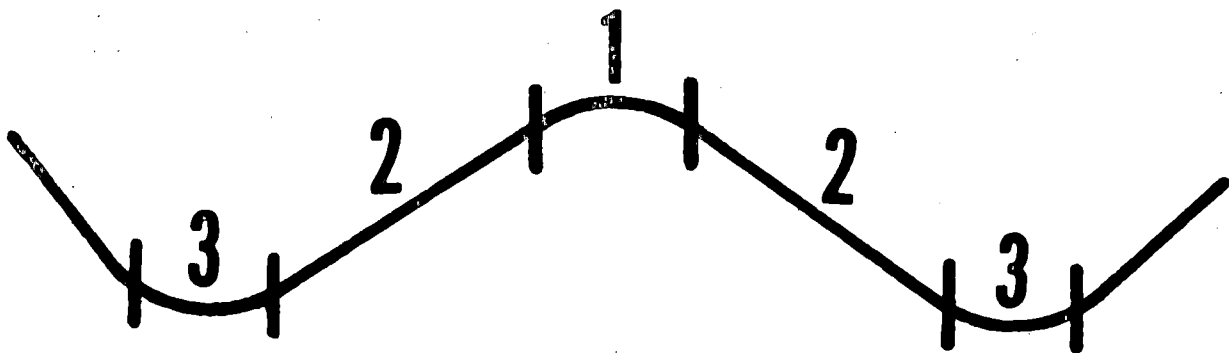


Figure 5. This hypothetical topographic cross section is a guide for assigning numerical values to topographic position.

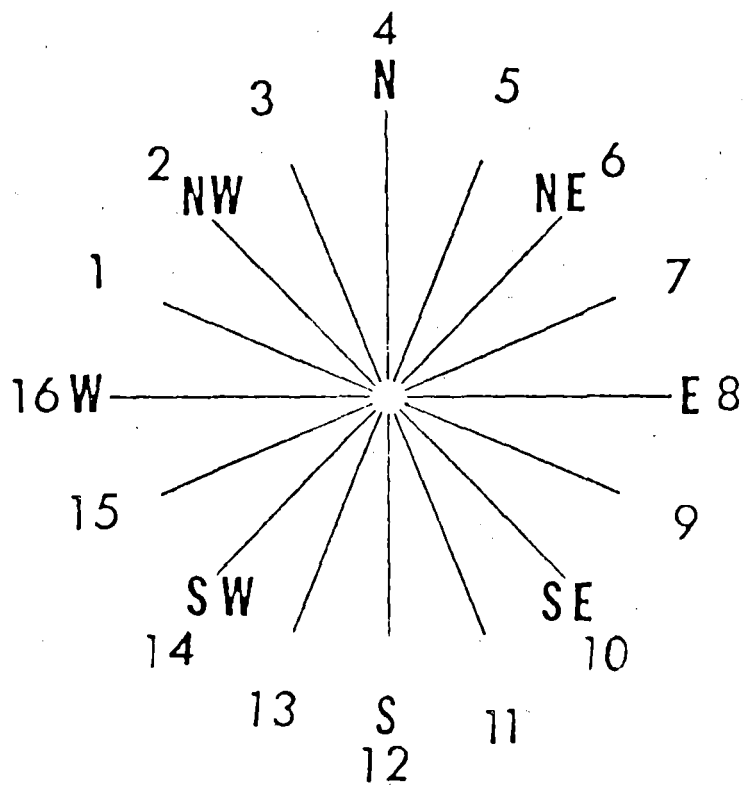


Figure 6. Template used for measuring aspect on aerial photographs.

viewing the photos in stereo with the template in place.

Crown closure: For each plot the stand was either open (1) or closed (2). Open stands had a majority of the crown not touching, closed stands had a majority of the overstory crowns touching.

Stand levels: Each plot was evaluated as either a single-storied (1) or multistoried (2) stand. If the stand was generally composed of trees about the same height, with less than 10 feet separating the tallest from the shortest, it was classified as being a single-storied stand; if not, it was classified as multistoried.

Density: The proportion of each plot covered (crown coverage) by all species was estimated using Pope's tree cramming method (Pope, 1960).

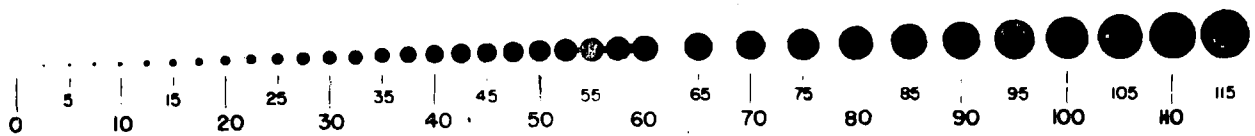
Purity: Stand/plot purity was defined as the proportion of fir species to all other species and was derived by dividing the crown coverage of fir by the crown coverage of all species. For example, if a plot had 70 percent open, 10 percent fir and 20 percent all species, purity would equal 50 percent.

Cosine of the aspect times tangent of the slope (COSA) and sine of the aspect times tangent of the slope (SINA): These variables were found to be simplest and most significant measures of radiation index on DFTM studies. These variables were used to analyze the amount of solar radiation reaching a stand/plot (Stage, 1975). Since aspect and slope have already been measured, their values need only be used in the computation of radiation index.

Crown diameter: A crown diameter template (Figure 7) was used for three dominant trees within the photo plot. The mean diameter in feet of the three trees was used.

CROWN DIAMETER SCALE

CENTRAL STATES FOREST EXPERIMENT STATION



NUMBERS INDICATE DOT SIZE IN THOUSANDTHS OF AN INCH

Figure 7. A crown diameter template was used to measure size of tree crowns.
Not to scale.

Defoliation information: Current defoliation was estimated on the large scale transparencies to the nearest five percent. After initial interpretation and subsequent ground examination, it was found that defoliation levels less than 40 to 50 percent were not apparent on the 1:4,000 scale photography. Although confidence was lower for defoliation levels below 50 percent, percentage values were still placed on these low defoliation plots. A visual comparison between the low defoliation plot in question and an area of known qualified low defoliation levels was used. There was a distinct tendency to overestimate current defoliation on trees with heavy past defoliation, and vice versa for low past defoliation. It was relatively easy to distinguish defoliation levels greater than 90 percent, but difficult to place percentage values on the defoliation levels ranging from 50 to 85 percent. Since we were aware of these discrepancies, an attempt was made to adjust for them.

4. ANALYSIS AND RESULTS

a. Pierce Area

Due to the lack of defoliation visible on the large scale (1:4,000) color photographs for Pierce in 1978, we were restricted to defoliation estimates taken on the ground. Two crews took five plot cluster samples in 10 stands (50 plots). Of these, we were only able to acquire large scale 1:4,000 photography for 9 stands including 36 plots. Using these limited data, we attempted to identify general trends in independent variable significance and develop a preliminary model.

With only 9 stands and 11 independent variables to test, an expansion of the data base was attempted. By using each plot within

a stand as an individual sample, 36 photo plots could be used instead of 9 mean stand photo values. There are a number of problems associated with using the clustered plots as individuals including multicollinearity among independent variables and autocorrelation among residuals in the regression. In comparing the simple correlation matrices for each plot and the mean stand values, no significant increase or decrease in correlation resulted. This answered the problem of multicollinearity but a Durbin-Watson D statistic (Barr et al., 1976) showed significant autocorrelation among residuals. This means that using cluster sample data as if they were individual observations results in a clumping of residuals in the regression. Because of the data problems, the 1978 Pierce data were used only for purposes of evaluating various analysis techniques and in model development in a very general sense.

The first linear analysis applied to the 1978 data was a stepwise multiple regression. Since 1978 defoliation levels were so low, it was decided that a mean defoliation level (1971 to 1978) estimated by the ground crews would better reflect plot defoliation (Stoszek et al., 1979). A two-variable model including topographic position and percentage of fir (purity) was the best model, but explained only 17 percent of the variation in defoliation ($R^2 = .17$). A maximum- R^2 -improvement technique developed an identical model but showed that elevation and elevation squared terms used together greatly increased correlation. This means that the elevation term is quadratic with respect to WSB defoliation.

An all-possible-regression technique was applied, yielding a two-variable model (elevation and elevation squared) which explain

55 percent of that variation ($R^2 = .55$) in defoliation. The addition of a third variable, crown diameter, increased the R^2 to .59. There was no significant increase in correlation by the addition of more variables (Table 1).

The RISK computer program (Hamilton, 1974), which is a nonlinear regression technique for a dichotomous dependent variable (currently defoliated or nondefoliated), was applied. Because of the small data set, the RISK program did not completely stabilize and could not be relied upon for results, but the preliminary results produced an encouragingly broad range of defoliation probability estimates. RISK regression coefficients, student-t and chi-square values were calculated for a two and three variable model using both stand and plot data (Table 2).

b. Twisp Area

Linear regression techniques were applied to 1979 Twisp River data. The techniques included SAS stepwise multiple regressions (both backward and forward elimination), a SAS R-square all-possible-regression (Barr et al., 1976) and Rex-Fortran 4 system (Grosenbaugh, 1967). The Rex system, an all possible regression technique, is more complicated to use than SAS but was the best technique for screening the independent variables. The SAS techniques were most useful in generating statistics for the most promising models.

The initial Rex screening produced a four group model which included: (elevation, elevation squared, elevation cubed) + (slope, COSA, SINA) + stand closure + purity. This model had an R-square of .51. An SAS analysis of variance was then applied to 11 models with the highest R-squares in the Rex screening. The analysis of variance

Table 1. All-possible-regressions model using mean defoliation as dependent variable. Pierce Area.

Number in Model	R-Square	Variables in Model	N=36
1	.10582	Topographic position	
2	.55436	Elev, Elev Sq	
3	.59138	Elev, Elev Sq, Dia	
4	.62539	Elev, Elev Sq, Closure, Dia	
5	.64938	Elev, Elev Sq, Cosa, Closure, Dia	
6	.66976	Elev, Elev Sq, Cosa, Dia, Level, Slope	
7	.68205	Elev, Elev Sq, Cosa, Sina, Topo, Closure, Dia	
8	.68681	Elev, Elev Sq, Cosa, Sina, Topo, Closure, Dia, Slope	
9	.69303	Elev, Elev Sq, Cosa, Sina, Topo, Closure, Dia, Density, Slope	
10	.69832	Elev, Elev Sq, Cosa, Sina, Topo, Closure, Dia, Level, Density, Slope	
11	.70205	Elev, Elev Sq, Cosa, Sina, Topo, Closure, Dia, Level, Density, Purity, Slope	

Elev = Elevation

Sina - sin aspect x tangent of slope

Elev Sq = Elevation squared

Topo = topographic position

Dia = crown diameter

Level = stand level

Closure = crown closure

Density = crown density

Cosa = cosine aspect x tangent
of slope

Purity = percent host type

Table 2. RISK regression coefficients, Student-t and Chi-square values for two and three variable models. Pierce Area.

2 Variable Model

	Regression Coefficient	Student-t Values	χ^2
Bo (intercept)	-.011861	-1.1945	
elevation	.049577	1.1883	
elevation ²	-.000005	-1.1832	1.46
N = 9 (stands)			
Bo (intercept)	-.867016	-2.3837	
elevation	.035432	2.3524	
elevation ²	-.000004	-2.3174	11.31

3 Variable Model

	Regression Coefficient	Student-t Values	χ^2
Bo (intercept)	-.018439	-1.1450	
elevation	-.083888	1.1255	
elevation ²	-.000009	-1.1132	
crown diameter	-.172930	-.7743	3.43
N = 9 (stands)			
Bo (intercept)	-95.9246	-2.3873	
elevation	.040827	2.3566	
elevation ²	-.000004	-2.3197	
crown diameter	-.040251	-0.9256	22.78
N = 36 (plots)			

Note: A large student-t value means an increased variable significance and a small chi-square value (χ^2) indicates better correlation between actual and predicted events. The low student-t values for the stand models and the high χ^2 values for the plot model suggest poor models. This is due mainly to small data sets and autocorrelation problems.

showed that slope and the radiation index variables (COSA and SINA) were not significant at the 90 percent level and the variables were eliminated. Four models that were significant at the 95 percent level were selected for further analysis (Table 3).

Examination of scatter diagrams of model residuals versus predicted values and independent variables revealed a slight megaphone shaped pattern (Figure 8). This problem is common with percentage data like the percent defoliation dependent variable. After consultation with Kirk Steinhorst, a University statistician, it was decided that an arc sine square root transformation might better distribute the residuals about zero (Figure 9). The transformation was applied to both the Rex analysis and SAS analysis of variance. Although there was a slight improvement of fit (R-squares increased as much as four percent for our best models and the covariances were slightly reduced), the transformation did not result in a better distribution of the residuals about zero.

The best model for the Twisp River area included elevation, elevation squared, elevation cubed, stand purity and stand closure, and had an R-squared of .50 (Table 3, model 4). The elevation cubed term was added after an examination of stand elevation plotted against predicted defoliation suggested a sinusoidal elevation effect (Figure 10). A three dimensional plot of the relationship between the independent variables (elevation, purity, and crown closure) and predicted defoliation levels shows defoliation increases as percent host type increases, and that it also increases with elevation up to 3,400 feet and then decreases with elevation (Figures 11 and 12). Defoliation is also heavier in more open stands.

Table 3. Analysis of variance results for 4 best linear models. Twisp River study area, Okanogan National Forest. Dependent variable = percent defoliation (DEF) (n = 152)

Source	Degrees of Freedom	F-Value	PR > F	C.V.	R-Square
Model 1					
Model	3	37.91	.0001	58.0634	.43
Error	148				
Total	151				
Model 2					
Model	2	58.91	.0001	57.4788	.44
Error	149				
Total	151				
Model 3					
Model	4	34.74	.0001	55.5217	.49
Error	147				
Total	151				
Model 4					
Model	5	29.16	.0001	54.96	.50
Error	146				
Total	151				

Independent variables:

Elevation* = E, Elevation squared = E^2 , Elevation cubed = E^3 , purity = P,
crown closure = C

$$\text{Model 1 DEF} = -570.67871 + 42.42251E - 0.90274E^2 + .00594E^3$$

$$\text{Model 2 DEF} = 87.8364 - 1.95628E + 0.52983P$$

$$\text{Model 3 DEF} = -580.78812 + 40.98541E = 0.88574E^2 + .00592E^3 + 49446P$$

$$\begin{aligned} \text{Model 4 DEF} = & -668.07102 + 46.43597E - .99288E^2 + .00658E^3 + .53731P \\ & - 7.56268C \end{aligned}$$

* All elevation terms were divided by 100.

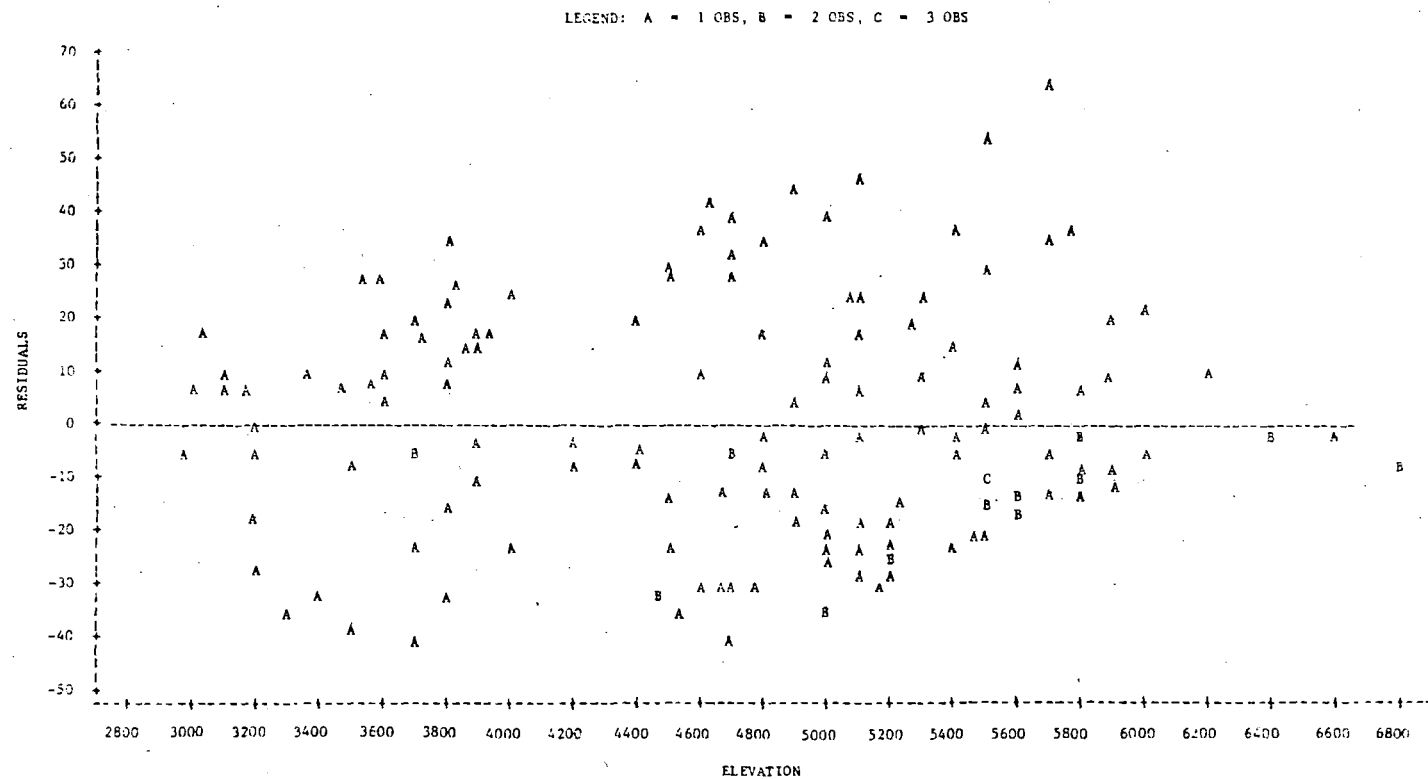


Figure 8. Plot of residuals for Twisp, Washington study area. 1979 data not transformed.

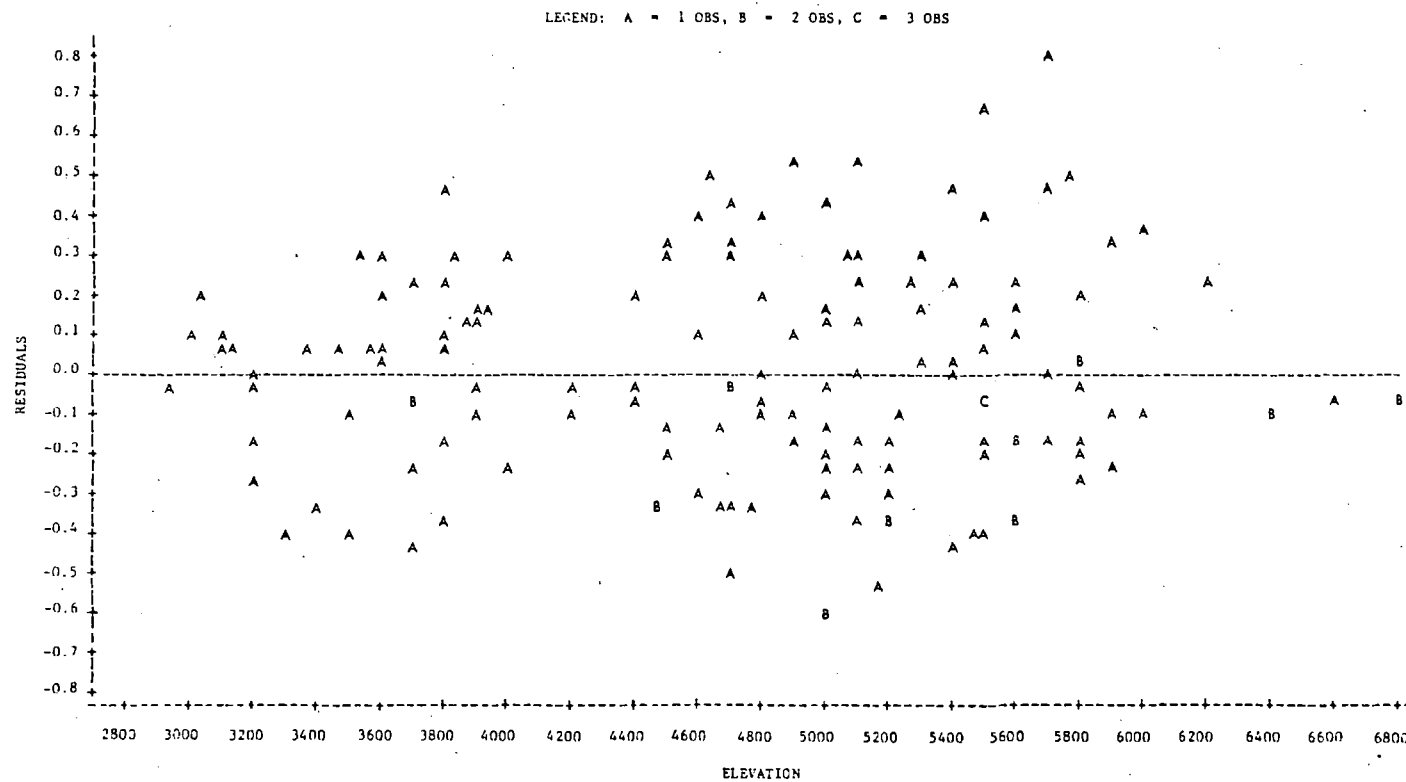


Figure 9. Plot of residuals for Twisp, Washington study area. 1979 data transformed.

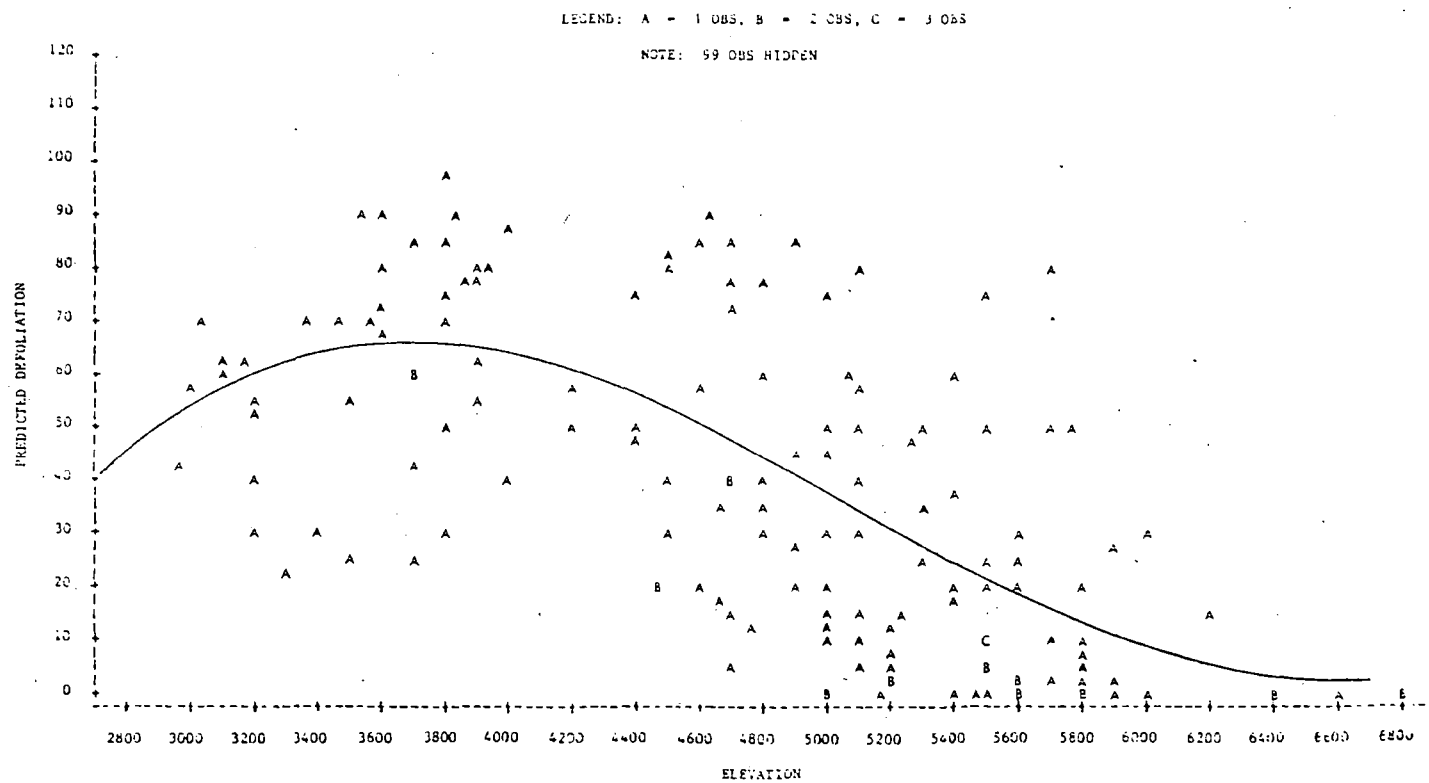


Figure 10. Plot of elevation by predicted defoliation for 1979 Twisp, Washington data.

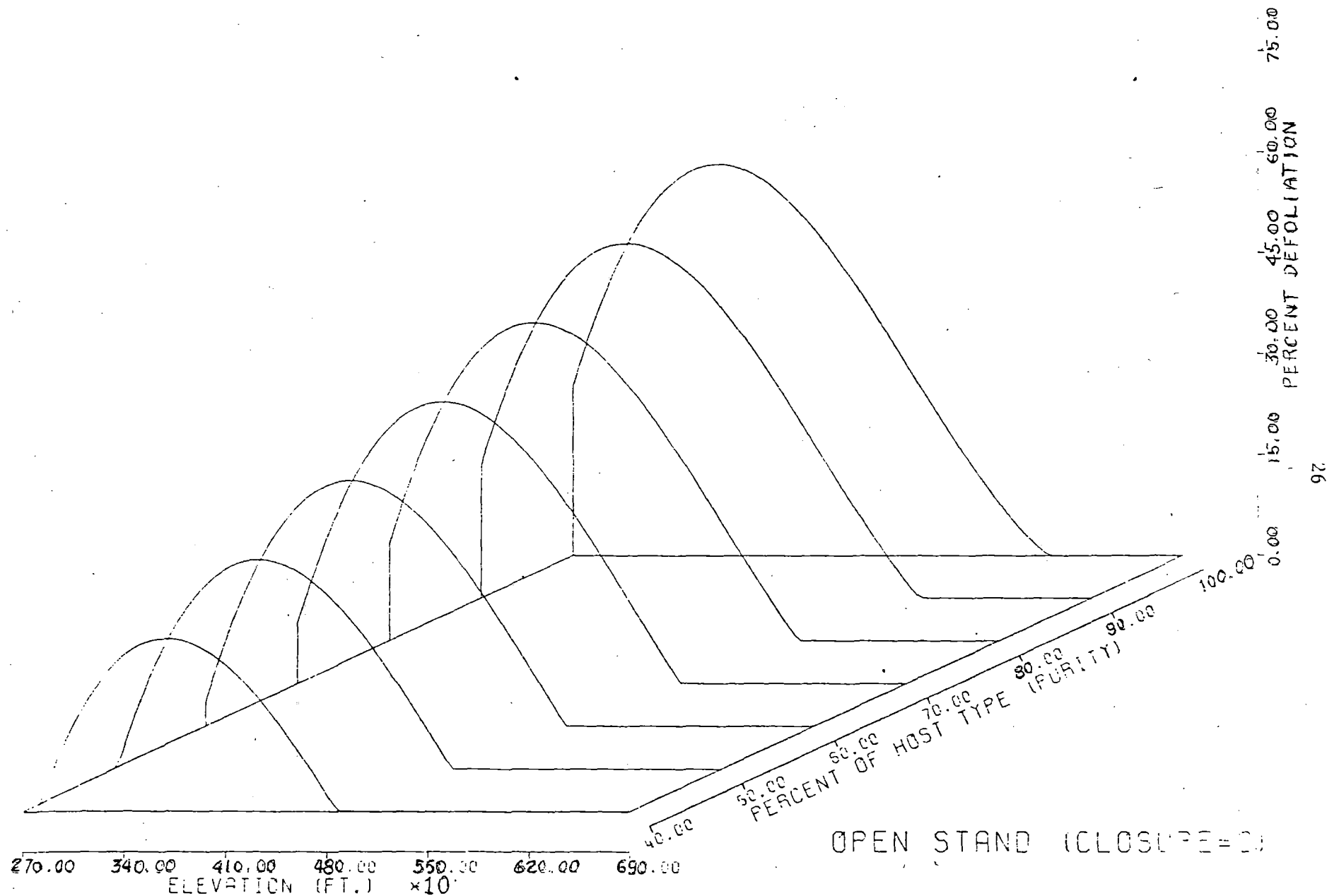


Figure 11. Three-dimensional plot of best linear model holding closure constant (closure = 0); Twisp River drainage, Okanogan National Forest. Predicted defoliations less than zero were plotted as zero. Note increased defoliation for open stand.

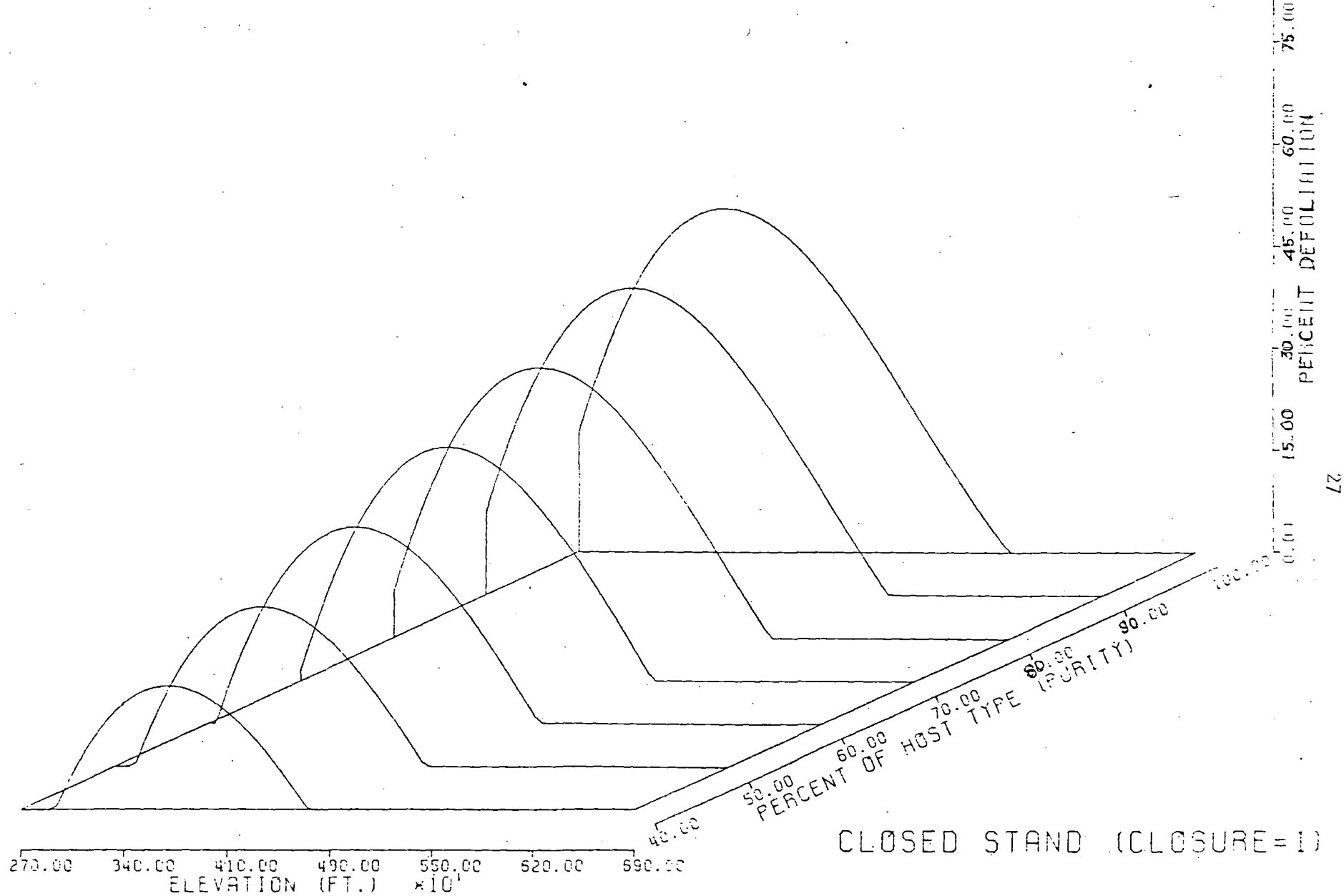


Figure 12. Three-dimensional plot of best linear model holding closure constant (closure = 1); Twisp River drainage, Okanogan National Forest. Predicted defoliations less than zero were plotted as zero.

The nonlinear RISK technique and a SCREEN program (Hamilton and Wendt, 1975) which screen the independent variables were applied to the data. The SCREEN program was not run in 1978 because the data base was too small. For Twisp approximately 600 photo plots were taken in 152 stands in 1979. This was a marginal number of stands for screening, but by screening the data in two steps (an initial screening, removal of the most significant variable, and screening again) two models were produced. Model A used a 50 percent defoliation level as a break off between defoliated and non-defoliated and Model B where a 10 percent break off was used (Table 4). The break off point for Model A (50 percent) was based on the point at which current defoliation was readily apparent and that was felt by several scientists studying WSB as being the point beyond which significant impact occurs. In Model B, it was assumed that defoliation levels below 10 percent were not significant. RISK programs were run on both models and the regression coefficients output were used to evaluate the models. A model evaluation program supplied by David Hamilton was used to generate predicted defoliation probabilities and to evaluate the two models. The program divides an independent variable into classes (stand density was used in our case) and compares the actual number of defoliation events in each class to the predicted number of events occurring in that class, given the supplied regression coefficients from RISK. A chi-square statistic is calculated for each class and summed for an overall chi-square value (Table 4). Both of the chi-square values are less than the chi-square table value of 12.4 for a .10 significance level. This leads to the conclusion that we cannot reject the hypothesis that actual and

Table 4. Chi-square statistics and variable costs for RISK models "A" and "B". Dependent variable = percent defoliation. Twisp Area.

Model A

Defoliated if current defoliation > 50 percent.
 Independent variables = elevation, elevation squared, crown diameter, purity.
 Overall chi-square = 12.04 (n = 20).

Model B

Defoliated if current defoliation > 10 percent.
 Independent variables = elevation, elevation squared, aspect, crown diameter, density.
 Overall chi-square = 7.15 (n = 20).

Independent variables:

Elevation = E, Elevation squared = E^2 , Crown diameter = CD,
 Purity = PU, Aspect = A, Density = D.

Model A

$$P = \{1 + \text{Exp}(-3.35657 + .0010196E - .0000003E^2 - .0079469CD + .0559290PU)\}^{-1}$$

Model B

$$P = \{1 + \text{Exp}(3.00833 - .0091942E + .0000006E^2 + 1106160A + .0421032CD + .0200648D)\}^{-1}$$

Where:

P = probability in percent that the stand will be defoliated by western spruce budworm.

predicted defoliation levels are the same at the 90 percent confidence level. The model evaluation also produced an encouraging range of event probability values of 0 to 88 percent for Model A and from 12 to 99 percent for Model B.

c. McCall Area

After consultation with Steinhorst it was decided that the clustering effects of random photo plots within an aerial photographic block would probably be negligible. This was due primarily to low sampling percentage (10 percent) within blocks and relatively large block size (one square mile). An analysis of 1980 McCall data showed that there were indeed significant differences in current defoliation levels between blocks within strata (strata here being defoliation intensity as aerial sketch mapped in 1979). This indicates a clustering effect of current defoliation within blocks. Operationally, including blocks in a regression for predicting defoliation makes a hazard rating needless. In order to include a block term in the prediction equation, the current defoliation level for a block must be known. If the defoliation level for a block is known, it makes no sense to try to predict an artificial one. For this reason and the fact that aerial photographic sample blocks are a meaningless boundary in terms of forest management, the one acre aerial photo plots were used as individual data points.

An interesting sidelight to the analysis of clustering effects was in the shifting of defoliation intensities from 1979 to 1980. The analysis showed a significant difference between defoliation class as sketch mapped in 1979 and defoliation levels as interpreted on large scale (1:4,000) 1980 color aerial photography (Table 5).

Table 5. Duncan's multiple range test comparing mean defoliation levels as interpreted in 1980 for all aerial photographic sampling blocks with 1979 aerial sketch map defoliation class. McCall Area.

Grouping	1980 Mean Defoliation (%)	N	1979 Defoliation Class
A	42.114286	175	Moderate
B A	37.5	60	Light
B	36.004728	423	Heavy

Alpha Level = .05; DF = 646; MS = 297.788

Means with the same letter are not significantly different.

There are a number of factors that could account for this:

1. That there indeed was a significant change in defoliation intensities.
2. The aerial sketch maps are incorrect.
3. The photo interpretation of defoliation is incorrect.

Assuming that aerial photo interpretation is at least as accurate as sketch mapping for estimating current defoliation levels, it is probably a combination of all three. The change in defoliation levels plus the high variances in defoliation rates within sketch map intensity classes and interpretation errors in lower defoliation levels probably accounts for these differences.

1) Regression Analysis

Linear regressions similar to ones used on Pierce and Twisp data were applied to 1980 McCall data. It was hoped that the McCall data would validate the findings from Pierce

and Twisp. In response to suggestions by Lyle Calvin of the Oregon State University Department of Statistics, an attempt was made to split the McCall data set using part to develop a model and the remaining data to validate the model. A two-thirds one-third split was used; two-thirds of the sampling blocks were used for model development and the remaining one-third for validation.

The initial Rex screening produced a model which included elevation, elevation squared, elevation cubed, slope, cosine of aspect times tangent of the slope, sine of aspect times tangent of the slope, density, stand level, topographic position, and purity as the best model with an R-square of .37. Eleven of the most significant models were selected and an analysis of variance on those models was used to reduce the number of potential models to five. Plots of these five models produced results similar to those for Twisp. The residuals seemed to be distributed in a megaphone shaped pattern about zero. An arc sine square root transformation again was applied as it was in Twisp with similar results. Although there was an increase in R-square values of approximately two to four percent, the pattern of residual distribution did not change. The best overall model produced from two-thirds of the data set included: elevation, elevation squared, elevation cubed, topographic position, crown diameter and purity with an R-square of .38.

A chi-square statistic was calculated for the remaining data using the coefficients from the best model. The calculated

chi-square value was 3012, much greater than the critical table value at the .05 significance level with 224 degrees of freedom. This means that the model developed for the two-thirds data set was doing a poor job of predicting defoliation for the remaining data.

Mean values for all variables, dependent and independent, were calculated. The mean values were examined to see if splitting the data set may have biased the results. It was discovered that mean elevation was indeed different between blocks and that two blocks in particular had mean elevations significantly higher or lower than the other blocks, and both blocks were in the large data set. With all the high and low elevations in the large data set and the elevation response seeming a cubic or sinusoidal function (elevation + elevation squared + elevation cubed), it was behaving quite differently in the tails or extremes with response to defoliation. In other words, the elevation response was quite different between the data sets because of only a few observations at high and low elevation in the large data set and no observations at high and low elevation in the small data set. Because of this and the clustering effect of defoliation within blocks, a random plot allocation to data sets was done. Individual plots were randomly assigned to a data set regardless of block and approximately a two-thirds, one-third split. Once again it was discovered that the model developed with the large data set was not working for the small data set.

A chi-square statistic was calculated for the entire data set using regression coefficients from the best model of the large data set. The results showed that the model could not be greatly improved by using all the data to develop a model. One significant finding when comparing models developed from the entire data set and the split data set was that the elevation cubed term dropped out. It seems that the unequal splitting of the elevation term had misrepresented the data and that the elevation effect for McCall was quadratic instead of cubic with response to defoliation. The best model for the McCall data included: elevation, elevation squared, topographic position, crown diameter and purity (Table 6). The difficulties with predicting defoliation for the small data set were due to weakness of the model. With an R-square of only .25 there is still 75 percent of the variation in defoliation not accounted for.

2) Nonlinear Analysis

Nonlinear analysis for the McCall data was accomplished again using the SCREEN and RISK programs. The SCREEN program was run using various defoliation break offs. Screening the data produced results similar to those of the linear analysis. As in the linear analysis purity and elevation were the most significant predictors. Aspect also was screened as significant but was not significant in the linear analysis and was the most important variable after purity and elevation. Because of the way defoliation was distributed for the McCall data a 20 percent defoliation break off was used. Using a 20

Table 6. Anova table and parameter estimates for model defoliation = $\sum \beta_i X_i$ (McCall area).

Source	df	Sum of Squares	Mean Squares	F	PR > F
Model	6	92068.9256	15344.8277	37.14	.0001
Error	651	268996.9915	413.2058		
Corrected Total	657	361065.9574			

X_i	β_i	$\sigma(\beta_i)$	F	PR > F
Intercept	-332.87803	53.29050	36.72	.0001
Elevation	0.12217	.01889	41.84	.0001
Elevation squared	- 1.07203-5	1.64-6	42.50	.0001
Topo. position			7.41	.0007
Ridge	- 6.08879	1.61020	14.30	.0002
Sidehill	2.35495	1.16078	4.12	.0429
Bottom	3.73384	1.98498	3.53	.0604
Crown diameter	- 0.68768	.22511	9.33	.0023
Purity	0.39697	.036160	120.52	.0001

percent break off assured adequate sample size for the non-defoliated class of the dependent variable (defoliation).

RISK runs were made on various permutations of variables found significant during screening and also for the best linear models. During the RISK analysis it was discovered that the elevation squared variable could not be included directly because its high correlation with elevation resulted in matrix singularity problems during calculations of regression coefficients. After personal communication with David Hamilton of the Forestry Sciences Laboratory, it was decided to use another term to represent elevation squared. The overall mean elevation for the McCall plots was determined and each plot elevation was subtracted from the mean and then squared. This was successful in elimination of the singularity problems and the resulting variable was very significant.

The overall best model developed included: elevation, elevation minus mean elevation squared, crown diameter, topographic position, and purity (Table 7). The overall chi-square for the model was 4.89. The predicted defoliation probabilities ranged from 4 to 99 percent. For the McCall area a forest stand around 6000 feet in elevation, with narrow crowned trees, on lower slopes and stream bottoms, and a high proportion of host to non-host trees has a higher probability of being defoliated by WSB.

Table 7. Best RISK model and defoliation prediction equation developed for McCall, Idaho 1980 data.

Independent Variables	Student T-Values	Regression Coefficients
Y-Intercept	.2279	.363206
Elevation in 1000 ft. (E)	.0966	.1964589
Elevation in 1000 ft. (E) *	-4.6169	-1.04756
Topographic position (Top 1) **	-3.8871	- .891844
(Top 2)	-0.0073	- .00141215
Crown diameter (CD)	-1.3610	- .0447395
Purity (PU)	7.9671	.0386609
Overall $\chi^2 = 4.89$		

* E is the difference in plot elevation from the mean elevation from all plots quantity squared.

** Top 1 and Top 2 are dummy variables (0 or 1) used to represent the class variable topographic position.

$$P = \{1 + \text{Exp}(0.363206 + 0.1964589E - 1.04756E - 0.891844\text{Top 1} - .00141215\text{Top 2} - .0447395\text{CD} + .0386609\text{PU})\}^{-1}$$

Where:

P = probability in percent that the stand will be defoliated by western spruce budworm.

5. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Results of this study indicate that WSB is indeed exhibiting site preferences, and these preferred sites can be identified using data obtained through remote sensing techniques.

The linear regression results developed significant models, but those models were too weak to produce an acceptable prediction of defoliation. The nonlinear RISK program on the other hand produced significant models and acceptable predicted defoliation values. This is due mainly to the broad brush approach of using a dichotomous dependent variable. Similar results would be expected using a dichotomous dependent variable in a linear analysis. The RISK models have not been validated.

*Next
year*

In all study areas, two independent variables, elevation and some quadratic or cubic form of elevation, and percent of host type (purity) were always screened as being the most significant independent variables. Other variables entered into the prediction models depending on the area. This means that each area under consideration for development of a hazard rating model should localize any models developed outside the immediate area. A point of consideration is that all the study areas this project concentrated on were predefined and existing WSB outbreak areas. This means that using models developed in outbreak areas for use in areas without a history of WSB problems may not be valid. However, in western United States, state and Forest Service Regional offices have sketch maps of previous WSB outbreaks and forest managers should ascertain that their forest stands have been subject to past WSB outbreaks before applying the RISK model.

Hazard rating models developed from remotely sensed data are not an attempt to explain the biological reasons for site preferences. The models

are strictly a reflection of those reasons at the macro level. There are any number of host/pest interactions which can be inferred and quantified to explain the observed variances in WSB site preference. The forest manager needs to know these specific biological interactions but he also needs information on a broader scale. A hazard rating model can fill that information requirement and supply the necessary data for such things as which areas to concentrate on given a WSB problem. Hazard rating models may also be used to interface with other stand growth and insect dynamic models.

A WSB hazard rating model can be developed on the broadest scale using only elevation and some cubic or quadratic form of elevation (depending on the area) and the percent of host type for a particular area. At this level it would not be necessary to use a defoliation prediction equation but simply to subjectively assign a hazard class to a particular area based on its elevation and percentage of host trees. A more refined model would ^{needed} be to actually predict a probability of a defoliation event occurring and ~~assigning hazard classes to these event probabilities.~~

A pilot study should be completed for any area (national forest, etc.) in which a hazard rating model is to be developed. The variables that should be included in a pilot study area: elevation and both a quadratic and a cubic form of elevation, percent of host (purity), crown diameter, stand or plot density, aspect, topographic position, and current defoliation level. These variables are identifiable on standard resource scale aerial photographs or maps with the exception of defoliation and purity. Defoliation and purity are obtainable from large scale (1:4,000) or larger aerial photography, ground visits, or timber cruise data.

The results demonstrate that aerial photography and remote sensing

techniques can be an effective tool in the isolation of forest stands susceptible to defoliation by western spruce budworm. A nonlinear regression computer program "RISK" was successfully used to develop a significant defoliation prediction model. Development of any operational hazard rating scheme should be preceded by a pilot study to determine regression coefficients and independent variable significance for inclusion in a prediction equation.

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6. SIGNIFICANCE OF RESULTS TO PROGRAM

The nonlinear RISK and SCREEN models derived from the McCall data provide the forest manager an analysis method to rate the hazard to his fir stands from western spruce budworm. The model should be validated on currently infested stands to determine the percent of correct predictions and whether improvements are indicated.

The authors believe that an aerial method of some kind is required on an insect problem that covers vast areas of western United States. Ground methods alone would be inefficient in terms of time, manpower requirements and cost. While this risk rating system describes only the likelihood of budworm attack, it should be coupled with other ground studies related to insect populations and silvicultural site/stand conditions to help assess expected level of damage.

7. WORK REMAINING ON STUDY

The research work has been completed. It would be desirable to undertake a validation study of the model. Probability predictions of host susceptible stands should be attempted over two to three watersheds within the boundaries of known defoliated areas.

Since there were only 13 satisfactory examples of defoliated host trees, it would be desirable to make additions to the photo handbook.

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Contract

8. COOPERATION AND COORDINATION

a. Forest Service, USDA personnel provided us with the following assistance:

- 1) James Colbert, Research Coordinator, arranged for a statistical review of our study plan with Dr. Lyle Calvin of Oregon State University prior to analysis of the 1980 field data.
- 2) Albert Stage and Dave Hamilton, Research Scientists, advised and assisted us with statistical programs. IF & RES, Moscow, Idaho.
- 3) Donn Cahill, Entomologist, provided aerial sketch maps and liaison with district and supervisor offices on the Payette and Boise National Forests. Forest Pest Management, S & PF, Boise, Idaho.
- 4) Roy C. Beckwith, Research Entomologist, cooperation in locating areas, reporting budworm population and defoliation conditions. PNWF & RES, Corvallis, Oregon.
- 5) Dennis Ferguson and Marvin Foiles, Research Scientists, cooperation in selecting study sites on Payette and Boise National Forests. IF & RES, Moscow, Idaho.

b. Others:

- 1) Karel Stoszek and Peter Mika, Research Professor and Research Associate, respectively, advice, cooperative planning, and assistance during data analysis. College of FWR, University of Idaho, Moscow, Idaho.

9. PROBLEMS ENCOUNTERED

We were unable to get satisfactory 70 mm color and color infrared aerial photographs because of aerial camera malfunctions. Therefore, that portion of the study was not accomplished; however, the mathematical model was developed with the smaller scale color film.

It would have been desirable to obtain more usable ground defoliation photos. The bulk of the foliage discoloration may have been washed off by the time the ground photos were taken. An effort should be made to supplement the 13 examples in the descriptive photo manual.

10. TECHNOLOGY TRANSFER - MANUSCRIPTS

- a. A validation study, using the RISK model, should be attempted to determine the efficiency and usefulness of the model under pilot study conditions.
- b. Hal N. Anderson obtained his Master of Science degree in May, 1981 as a direct result of the support of his work by the CANUSA program. His thesis is on file at the University of Idaho Library and is entitled "Photo Interpretation Techniques Establish Hazard Rating Criteria for Western Spruce Budworm Susceptible Forest Stands."
- c. A handbook type publication is in preparation stages entitled "Recognition of Western Spruce Budworm Defoliation on Ground Photographs." It is intended to be used as a field guide for foresters and forest entomologists.

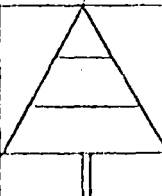
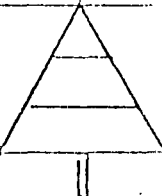
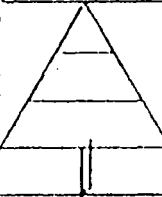
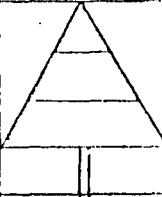
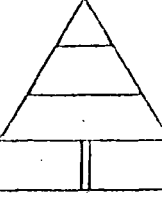
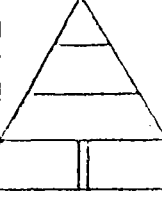
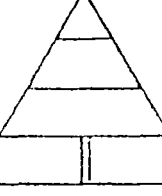
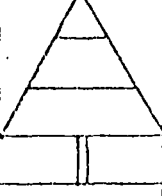
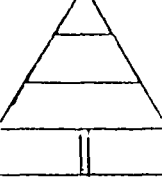
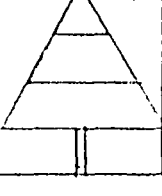
APPENDIX A

BLK No. _____ Date _____ Observers _____

[illegible]

PHOTO PLOT DEFOLIATION INFORMATION
OBTAINED ON GROUND

BLK NO. _____ DATE _____ OBSERVERS _____

Photo No.	Tree No.	Species	Height	Crn. Dia.	Ocular Defoliation		Past Defoliation					Remarks	
					Estimate %		Branch	Midcrown Branch					
					Current	Old		78	77	76	75		74
													
													
													
													
													

APPENDIX B

WSRW Photo Interpretation Form (Twisp Area)

H.N. Anderson

BL	ST	P	ELEV	S	AS	DIA	L	C	T	DEN	PUR	DEF	ETYP	MAT	SIZE	STK	REMARKS
2	8	1	4400	1	1	42	2	1	1	35	90	30					
		2		1	1	55	2	2	1	45	95	40					
		3		2	9	60	2	2	1	60	94	45					
		4		2	9	60	2	2	1	85	100	35					
		5		2	9	60	2	2	1	85	93	30					
Mean values				6	5.8	55.4	2	1.8	1	62	94.9	36.0					
27	13	1	3900	1	1	45	2	2	2	50	75	15					
		2		2	16	47	2	2	2	60	85	20					
		3		2	14	42	2	2	2	60	85	25					
		4		2	14	42	2	2	2	60	70	25					
		5		2	15	45	2	2	3	75	70	10					
Means				1.8	12	44.2	2	2	2.2	61	77.0	19.0					
34	5	1	5000	1	14	47	2	2	2	60	100	35					
		2		1	14	52	2	2	2	70	95	40					
		3		1	14	52	2	2	2	60	95	40					
		4		1	14	50	2	2	2	70	90	40					
		5		1	14	45	2	2	2	50	85	35					
Means				1	14	49.2	2	2	2	62	93.0	38.0					
34	8	1	4600	2	11	57	2	2	3	75	60	45					
		2		2	11	60	2	2	3	70	65	45					
		3		2	13	62	2	2	3	50	55	45					
		4		1	13	62	2	2	3	50	55	45					
		5		1	13	65	2	2	3	60	55	45					
Means				1.6	12.2	61.2	2	2	3	61	58.0	45.0					

BL = BLOCK

ST = STAND

P = PLOT

ELEV = ELEVATION

S = SLOPE

AS = ASPECT

DIA = DIAMETER

L = STAND LEVEL

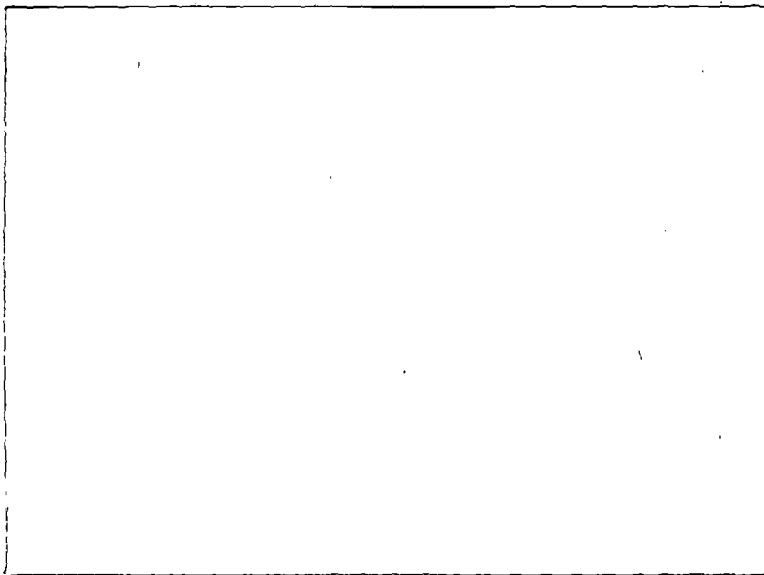
C = CROWN CLOSURE

T = TOPOGRAPHIC POSITION

DEN = DENSITY

PUR = PURITY

DEF = DEFOLIATION



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USDA Forest Service
240 W Prospect Rd
Fort Collins CO 80526